LXXXI. *A Deſcription of Two Methods, by which the Irregularity of the Motion of a Clock, ariſing from the Influence of Heat and Cold upon the Rod of the Pendulum, may be prevented*; *by* John Ellicott, *F. R. S.*

Read June 4, 1752.

THE firſt of theſe methods conſiſts in a particular conſtruction of the pendulum itſelf, which occurr'd to me ſeveral years ago. In the beginning of the year 1738, I put into the hands of Mr. Machin, then one of the ſecretaries, a deſcription and a drawing of ſuch a pendulum, in order to their being laid before this honourable Society: but Mr. Machin, ſoon after, acquainting me, that a gentleman, of whoſe ſkill and judgment in mechanical contrivances I had always entertain'd the higheſt opinion, made ſome objections, I was adviſed to defer communicating my invention to this Society, till I ſhould have examined into the weight of thoſe objections, and, by a fair and impartial trial, ſhould be fully aſſured, that the contrivance would anſwer the end propoſed. And having now at length obtain'd that ſatisfaction, I beg leave to give a ſhort narrative of ſome of the moſt remarkable obſervations I have made during this inquiry, which I hope will not prove unacceptable to this honourable Society.

About the year 1732, an experiment, which I made, in order to ſatisfy ſome gentlemen, that the rod of a pendulum was liable to be conſiderably influenced by moderate degrees of heat and cold, led me

me to conſider, that, as metals differ from each other in their denſity, it was highly probable they might likewiſe differ from each other in their expanſion; and that this difference of the expanſions of two metals might be ſo applied, as in a great meaſure to remove thoſe irregularities in the motion of a clock, which ariſe from the effect of heat and cold upon the length of a pendulum. With this view, not long afterwards I contrived the pendulum now deſcribed by Fig. 1.

In which *a b* repreſents a bar of braſs, made quite faſt at the upper part by pins, and held contiguous, at ſeveral equal diſtances, by the ſcrews 1, 2, 3, &c. to the rod of the pendulum, which is a bar of iron; and ſo far as the braſs bar reaches, is filed of the ſame ſize and ſhape, and conſequently does not appear in the figure; but a little below the end of the braſs bar, the iron is left broader, as at *d d*, for the conveniency of fixing the work to it, and is made of a ſufficient length to paſs quite thro' the ball of the pendulum to *c*. The holes, 1, 2, &c. in the braſs, thro' which the ſhanks of the ſcrews paſs into the iron rod of the pendulum, are filed as in the drawing, of a length ſufficient to ſuffer the braſs to contract and dilate freely by heat and cold under the heads of the ſcrews. *e e e e* repreſents the ball of the pendulum: *f f*, two ſtrong pieces of ſteel, or levers, whoſe inner centres, or pivots, turn in two holes drilled in the broad part of the pendulum-rod, and their outer ones in a ſtrong bridge, or cock, ſcrew'd upon the ſame part of the rod, but omitted in the draught; becauſe, when put on, it covers this mechaniſm. *g g*, are two ſcrews entering at the edge, and

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Fig. 1.
p. 480.

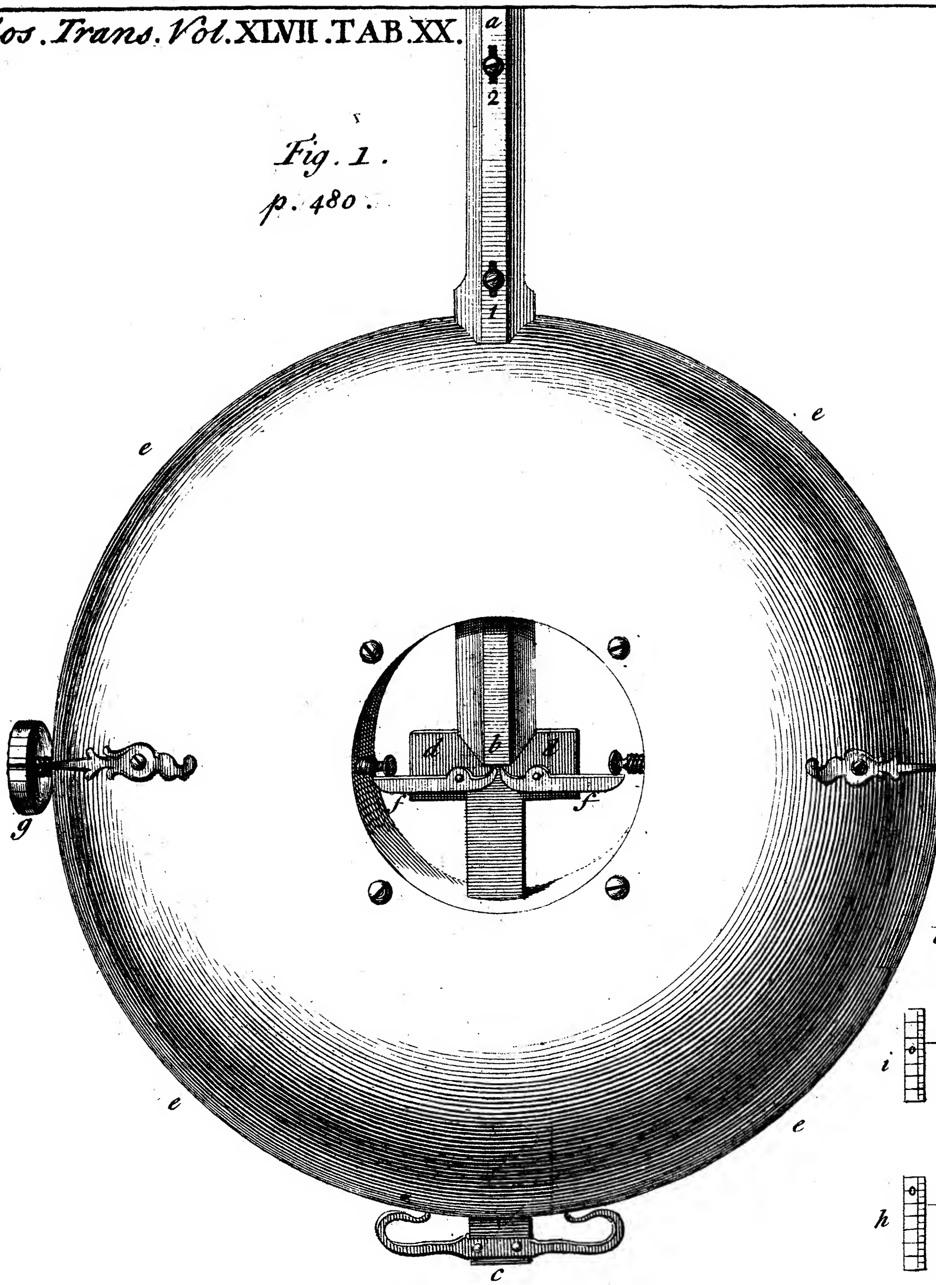

Fig. [cut off]
p. 48[cut off]

Fig. 2. p. 481.

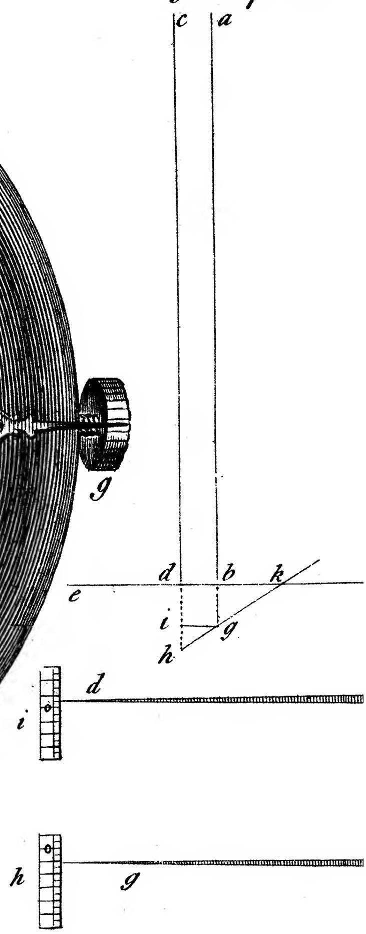

Fig. 3
p. 486.

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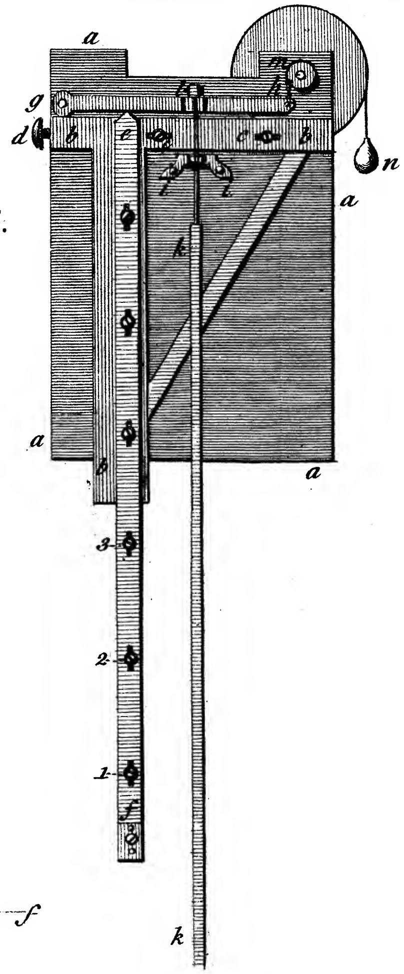

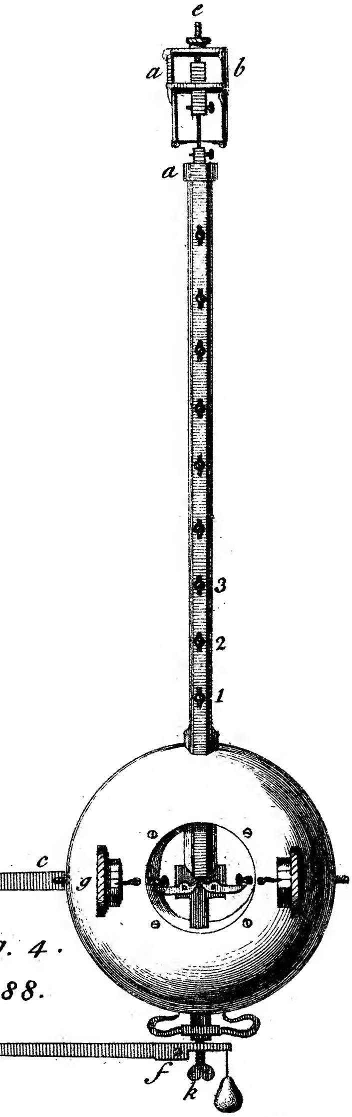

Fig. 4.
p. 488.

J. Mynde sc.

and reaching into the cavity near the centre of the ball. The ends of theſe ſcrews next the centre are turn'd into the form repreſented in the drawing, which, preſſing with the weight of the ball againſt the longer arms of the levers, cauſe the ſhorter arms to preſs againſt the end of the braſs bar at 6. Things being in this ſituation, let us ſuppoſe, that the rod of the pendulum, and the braſs annexed to it, grow longer by heat; and that the braſs lengthens more than the iron of the ſame length: then the braſs, by its exceſs of dilatation, will preſs the ſhort ends of the levers downwards at 6, and at the ſame time neceſſarily lift up the ball, which reſts upon the long ends of the ſame levers at *ff*, to any proportion neceſſary: And provided the ends of the ſcrews do preſs upon the levers at a proper diſtance from the centres, the ſaid ball will be always kept at the point of ſuſpenſion, notwithſtanding any alteration the rod of the pendulum may be liable to from heat or cold. What this diſtance ought to be, may very nearly be determined, if the difference of the expanſion between the braſs and iron bars is known; for the proportion the ſhorter arms of the levers ought to bear to the longer ones will always be, as the exceſs of the expanſion of the braſs is to the whole expanſion of the iron, as may be thus eaſily demonſtrated. Fig. 2.

Let the line *a b*, drawn perpendicular to the line *e f*, repreſent a bar of iron; the line *c d* a bar of braſs, the pricked line *b g*, the expanſion of the braſs bar by the ſame degree of heat: let the line *g i* be drawn parallel to the line *e f*, then will *i b* repreſent the difference of the expanſion of the two metals: thro' the points *b*, *g*, draw a right line

 cutting

cutting the line *ef*, as in *k*; this line may be supposed to represent one of the levers turning upon its centre at *g*, *h* the point where the brass bar acts upon the shorter end of the lever, and *k* the point where the screw acts upon the longer end of the lever, which being the place where it intersects the line *ef*, it is evident the ball of the pendulum will be as much raised by the lever, as it would have been depressed by the expansion of the iron; but the triangle *ihg* is similar to the triangle *bgk*; and therefore, as *ih*, the excess of the expansion of the brass, is to *bg*, the whole expansion of the iron, so will *hg*, the shorter arm of the lever, be to *gk*, the longer arm of the lever. *Q. e. d.*

At Fig. 1. is placed a strong double spring, whose ends pressing against the under edge of the ball, hinder it from bending the brass bar by its forcible action thereon at the point *b*, which, when the ball is of a considerable weight, it might otherwise be very liable to do.

The description here given is exactly agreeable to the original contrivance; and the only alteration I have since made in it, consists in placing the screws *gg* within the ball of the pendulum, as represented in Fig. 4.

But as the success of this contrivance depended intirely upon the supposition, that metals were expanded differently by the same degree of heat, before I attempted to put it in execution, I thought proper to inquire what experiments had already been made upon this subject, when Mr. John Eames, a late very worthy member of this Society, put into my hands Mr. Graham's account of his quicksilver pendulum

pendulum (as it is now commonly called) publiſhed in the *Philoſophical Tranſactions*, N° 392, which account I found to be introduced by the following paragraph:

" Whereas ſeveral, who have been curious in
" meaſuring of time, have taken notice, that the vi-
" brations of a pendulum are ſlower in ſummer than
" in winter; and have very juſtly ſuppoſed this al-
" teration has proceeded from a change of length in
" the pendulum itſelf, by the influences of heat and
" cold upon it, in the different ſeaſons of the year;
" with a view therefore of correcting, in ſome de-
" gree, this defect of the pendulum, I made ſeve-
" ral trials, about the year 1715, to diſcover whe-
" ther there was any conſiderable difference of ex-
" panſion between braſs, ſteel, iron, copper, ſilver,
" *&c.* when expoſed to the ſame degrees of heat,
" as nearly as I could determine; conceiving it would
" not be very difficult, by making uſe of two ſorts
" of metals differing conſiderably in their degrees of
" expanſion and contraction, to remedy, in great
" meaſure, the irregularities, to which common pen-
" dulums are ſubject. But although it is eaſily diſ-
" coverable, that all theſe metals ſuffer a ſenſible
" alteration of their dimenſion by heat and cold;
" yet I found their differences in quantity, from one
" another, were ſo ſmall, as gave me no hopes of
" ſucceeding this way, and made me leave off pro-
" ſecuting this affair any farther at that time."

The reading this paragraph proved at that time ſufficient to make me lay aſide all thoughts of ſucceeding in a contrivance founded upon principles, which a gentleman of ſo great abilities, and known

accuracy in making experiments, had, after trial, judged to be inſufficient. And it was not till about the latter end of the year 1734, that I again reſumed them on the following occaſion. A gentleman deſirous to make ſome experiments concerning the expanſion of metals, employ'd me to make him an inſtrument like one invented by Mr. Muſchenbroek for that purpoſe, which he calls a pyrometer. Upon looking over Mr. Muſchenbroek's experiments, I not only found the difference between the expanſion of ſome of the metals much greater than I expected, but, as I thought (if they were to be depended upon) ſufficient to anſwer my former purpoſe. This led me to conſider the ſtructure of the inſtrument, which Mr. Muſchenbroek made uſe of in his trials, and upon examination, I thought it liable to ſome objections, which I imagined would make the reſult of experiments made by his inſtrument very uncertain. I therefore endeavour'd to contrive one of a different conſtruction, that might be more to be depended upon. Such an inſtrument I ſome time afterwards completed, and had the pleaſure to find it ſo far met with the approbation of ſeveral very worthy members of this Society, that, at their particular deſire, I drew up a deſcription of it, which was read, and the inſtrument itſelf ſhewn to the Society on the 8 of April 1736 *: and though it was not in every reſpect

* This appears from the minutes of the Royal Society; tho' the deſcription and manner of that inſtrument was, by ſome miſtake, placed ſix months later in the *Philoſ. Tranſ. Vol.* XXXIX. N. 443. for October 1736. The other dates, mention'd in this paper, relating to that inſtrument, are likewiſe juſtified by authentic vouchers, which have been produced by Mr. Ellicott.

ſpect ſo accurate as I could wiſh, I am fully perſuaded, that ſuch experiments, as are carefully made with it, may be depended upon, as very near the truth. Having made a great variety of experiments with this inſtrument upon bars of different metals, as nearly of the ſame dimenſions as poſſible, I found, upon a medium, their ſeveral expanſions by the ſame degree of heat to be as follows:

Gold	Silver	Braſs	Copper	Iron	Steel	Lead
73	103	95	89	60	56	149

And as I found ſo great a difference between the expanſion of braſs and iron, I immediately determined to make a pendulum after the manner above deſcribed, compoſed of thoſe two metals, and likewiſe order'd a clock to be made, with the utmoſt care and exactneſs; and, as I then apprehended, with ſome conſiderable improvements, with which I intended to make the experiments. Theſe were both finiſhed in the beginning of the year 1738; and having no reaſon to doubt of ſucceſs, I ſhew'd the pendulum to the late Mr. Machin, and gave him a drawing and deſcription of it, in order to its being communicated to the Royal Society; but, as I have already obſerved, objections were made to it, of which the only one, that appeared to have any weight, was, that it had been found by experiment, that two bars of different metals, ſcrew'd together, ſo as to be in contact with each other, would not expand regularly and ſmoothly, but by jerks. In order to examine into the force of this objection, I directed two bars of equal dimenſions to be made, one of braſs, the other of iron, of about two feet in length, faſten'd together after the ſame manner, as the two rods of the pendulum,

pendulum, which I intended to place ſo, that, by acting very near the centre of an index of a conſiderable length, even the ſmalleſt alteration in the bars would be made ſenſible, and by the motion of the index I ſhould be able to form a judgment, whether the rods moved regularly and freely, or not: but before this was put into execution, I contrived, by faſtening the two bars to the back plate of a clock, not only to make them anſwer the end above propos'd, but, at the ſame time, to lengthen or ſhorten a pendulum of a common conſtruction, in ſuch a manner, as ſufficiently to correct the irregularities ariſing from the influence of cold or heat upon it. The manner of applying them is deſcribed by Fig. 3.

In which, *a a a a* repreſents the back plate of the clock, *b b b*, a triangular piece of braſs, ſcrew'd by two ſcrews, thro' the ſlits *c c*, to the plate, yet ſo that it may be drawn backwards or forwards by means of the ſcrew at *d*. *e f* is a braſs bar, about two feet in length, made faſt at the bottom, by a ſcrew and two pins at *f*, to an iron one of equal dimenſions, to which it is likewiſe ſcrew'd by the ſcrews 1, 2, 3, *&c.* after the ſame manner as the rod of the pendulum already deſcribed. The iron bar is faſtened at the upper end to the triangular piece of braſs, nearly under that part of the braſs bar marked *e*. *g h* is a ſtrong braſs or iron lever, moveable upon a centre at *g*, and is ſupported by the upper end of the braſs bar; *i i* is the cock, on which, in a common clock, the pendulum is hung; *k k*, part of the rod of the pendulum, whoſe ſpring paſſing thro' a fine ſlit in the cock *i i*, is faſten'd to a ſtud riveted into the lever at *l*. The ſlit in the cock

muſt

muſt be made ſo cloſe, as to prevent the ſpring from having any lateral motion in it.

From this deſcription it is evident, that, if the braſs bar expands more than the iron one, it will raiſe up the lever, and, conſequently, the pendulum, which is faſten'd to it; and, as the length of the pendulum is only from the centre of oſcillation to the under part of the ſlit, thro' which the ſpring paſſes, the pendulum will be thereby ſhortened; and, by making the point of the braſs bar to act upon a proper part of the lever (to which it is capable of being adjuſted by means of the ſcrew *d*) the pendulum may be ſhortened to whatever degree ſhall be neceſſary.

To prevent the pendulum from bending the bars, which it would be liable to do, if the ball of the pendulum was of any conſiderable weight, the end of the lever, fartheſt from its centre of motion, is hook'd to the end of a chain, which is wound about and faſtened to a ſmall pulley at *m*. Upon the ſame arbor, to which this pulley is fixed, is faſtened another pulley, of a much larger diameter, to which is hung, by a ſilk line, the weight or counterpoiſe *n*. By means of this counterpoiſe, any part of the weight of the pendulum, that ſhall be deſired, may be taken off from preſſing againſt the braſs bar. And if, upon the end of the arbor, to which the pullies are fixed, an index be placed, ſo as to point to a graduated circle, the leaſt motion of the lever will not only be eaſily perceived, but alſo whether that motion is uniform and regular, or not. And upon having, ſome time after, made a clock with this contrivance added to it, I had the pleaſure to find the index not only to move very ſenſibly, but very regularly, and never,

that

that I could perceive, by jerks. And I doubt not, but, when the point of bearing of the brafs bar upon the lever is once well adjufted, it will be found to lengthen or fhorten the pendulum to as great a degree of exactnefs, as any other method whatfoever. But, as I have not as yet thought of any other method of adjufting it, except from actual trial in different feafons of the year, I muft prefer the pendulum to this method, which, from the great eafe, as well as exactnefs, with which it is capable of being adjufted, will, I think, appear to have much the advantage over any other contrivance yet made ufe of for this purpofe.

The method I take for adjufting the longer arms of the levers of the pendulum to the fhorter ones is defcribed in Fig. 4. To a ftrong poft, fixed to the wall, is faftened a fmall fhelf, fupported by two brackets *a b*. In the middle of this fhelf is faftened a wire, by the fcrew *e*; to the end of which the pendulum is to be hung. Below this fhelf, at the diftance of about 40 inches, is placed the index *c d*, turning freely upon a center: The length of the index is 50 inches. At the diftance of half an inch, upon a part of the index produced beyond the centre, is placed a fteel pin; and in the back of the pendulum, as near the centre of ofcillation as may be, is drilled an hole to receive this pin; when the pendulum is hung upon the wire againft the poft, and the wire is fcrew'd higher or lower by the fcrew *e*, till the pin refting againft the upper part of the hole (which is filed into a proper fhape for that purpofe) keeps the index nearly in an horizontal pofition. Below the bottom of the pendulum is placed a fecond index

index *fg*, exactly like the former, except that it is kept in an horizontal poſition, by the ſcrew *k* bearing againſt the end of the iron rod. When the experiment is to be made, the pendulum is firſt put into a box, and gradually heated by a large fire, to a conſiderable degree, being often turned, that every part may be equally expoſed to the fire. And having continued ſhut up in the box for ſome time after it is removed from the fire, that the two rods may be heated as uniformly to the ſame degree as poſſible, the pendulum is hung upon the wire, and the two indexes made to ſtand nearly in an horizontal poſition. The two graduated plates *h i* are then ſlid upon a wire, till the diviſions in each mark'd *o* are pointed to by the indexes. As the pendulum cools, the lower index will be ſeen gradually to deſcend; but if the ends of the two ſcrews, in the ball of the pendulum, act upon proper parts of the levers, the upper index will continue in the ſame place. If the ends of the ſcrews are either too far off, or too near the centres of the levers, the index will either riſe or deſcend; and, by comparing the number of diviſions it has varied, with thoſe which the lower index has varied, a near eſtimate may be made, how much the ſcrews require to be alter'd; and, in a very few trials, they may eaſily be adjuſted to a very great exactneſs. In order to make an actual trial, how far this contrivance of the pendulum will anſwer the end propoſed, it is neceſſary, that the clock, to which the pendulum is fitted, be made with great exactneſs, and intirely to be depended on: For otherwiſe the experiments will be very uncertain, as I found in the clock I firſt made uſe of.

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I have already obſerved, that, in order to render this clock as perfect as poſſible, I made it, in ſeveral reſpects, different from the common ones, in hopes of removing ſome imperfections I apprehended they were liable to. But as, in this attempt, I fell into an error, which it was a conſiderable time before I diſcover'd, my making the trial was thereby greatly retarded. And in order to prevent others from falling into the like miſtake, I ſhall beg leave to give ſome ſhort account of it.

In a common clock the pendulum is uſually hung by a ſpring to a cock on the back plate of the clock, whilſt the wheel and pallets, by which the pendulum is kept in motion, are placed in the middle of the frame; and the pendulum is moved by a piece of ſteel (call'd the crutch) riveted to one end of the arbor, to which the pallets are faſtened. This diſpoſition of the pieces I apprehended liable to ſome conſiderable objections: To remedy which, I contrived to fix the pallets to the upper part of the pendulum itſelf, above the centre of motion; and, in order to make the pendulum vibrate as freely as poſſible, it was made to turn upon two ſteel points, and was hung in the middle of the frame, exactly under the ſwing-wheel, and ſo as to vibrate in the ſame plane with it. By this means I was in hopes, that it would have moved with much greater freedom and regularity, than when hung after the common method; and, upon trial, it was found to move with ſo great freedom, that a pendulum of above 20 pounds weight, when hung in its place without the clockwork, and made to vibrate thro' an arch of two degrees, was found to make above

1200

1200 vibrations, before it had loſt half a degree, and was obſerved to have a ſenſible motion above 20 hours afterwards; and the clock, when firſt put together, was kept going, for ſeveral days, by a weight of only eleven ounces, hung to the end of a ſingle line. But it was not long, before I diſcover'd, that this great freedom made it liable to be conſiderably affected by the leaſt motion.

A remarkable inſtance of this I communicated to this Society, which was publiſhed in the *Philoſophical Tranſactions*, N° 453. But the greateſt objection to this method was, the points being ſubject to wear; and I found, that the leaſt alteration in them would occaſion the clock to vary much more, than (without having made the trial) I could have imagined. To remedy this inconvenience, I made the pendulum to move upon edges, like thoſe, on which the beam of a pair of ſcales turns (a method I had good reaſon to believe had been made uſe of with ſucceſs); but I found theſe likewiſe liable to wear, tho' not in ſo ſhort a time as the points; ſo that, after much time ſpent in making ſeveral experiments, in order to remedy this inconvenience, I found myſelf obliged to lay this method wholly aſide, and to hang the pendulum upon a ſpring, as uſual.

In making this alteration, I obſerved one circumſtance, which I think deſerves to be taken notice of. Before I made any alteration in the work, I took particular notice to what height the pendulum required to be raiſed, before the pallets would eſcape from the wheel. I next obſerved the number of degrees of each vibration of the pendulum, when mov'd by the clockwork; and then, the clockwork being remov'd,

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the pendulum was made to defcribe an arch of two degrees; and particular notice was likewife taken, in what fpace of time it had loft half a degree each vibration. Having then made the neceffary alterations for hanging the pendulum by a fpring, and particular care being taken that the pallets fhould fcape off from the wheel exactly at the fame angle as before, the pendulum being hung by its fpring, and made to vibrate thro' an arch of two degrees, it was obferved to lofe half a degree in about half the time it did when turning upon edges. But, upon being fet a-going by the clock-work, the pendulum was found to defcribe an arch of near two degrees more than before: For, when it turned upon the edges, it defcribed an arch of only three degrees; whereas, now it was hung by the fpring, it vibrated near five degrees; which was very different from what I expected.

This alteration being made, I foon found, that the clock went very regular; and, after a fufficient trial, was fully fatisfied the pendulum would anfwer my expectations. But, fearing left I might be thought prejudiced in favour of my own invention, I engaged the Rev. Mr. Profeffor Blifs to make trial of it; and. accordingly, in the beginning of the year 1750, I fent to him, at Oxford, a clock for that purpofe; and, in January laft, I received from him a letter, giving his opinion of it, of which the following (fo far as relates to the clock) is an exact copy.

" SIR,

" I have now had thorough trial of the clock;
" and am perfectly fatisfied, that your pendulum
" takes

" takes off the effect of heat and cold as well as " either the gridiron-pendulum (as it is com- " monly called) or the quickfilver pendulum; and " this upon fufficient trial for near two years. It has " this advantage of both the fore-mention'd ones, " that it may, by lengthening or fhortening the " levers, be eafily adjufted to the exact proportion " of the difference of the iron and brafs, which nei- " ther of thofe kinds is capable of, without very " great trouble and difficulty. I was indeed preju- " diced againft the method of doing it by levers, as " I had heard the late Mr. Graham fay, that he had " tried levers in different ways, that he found they " did not work regularly and freely, but by jerks. " However, in your method, I am fatisfied, by the " fulleft experience, that they fucceed as well as " either of the other forts, or perhaps any other kind, " that may be invented hereafter."

Before I conclude this paper, I fhall beg leave to acquaint this honourable Society, that, in the year 1748, I made a model of a contrivance to be added to a pocket-watch, founded upon the fame principles, and intended to anfwer the like purpofe, as the pendulum above defcribed. And, at a meeting of a council of this Society, on February 15 laft, I produced a watch (which I had made for a gentleman) with this contrivance added to it, and likewife the model, by which was fhewn to the gentlemen then prefent what effect a fmall degree of heat would have upon it. But, as I have not yet had fufficient trial of this watch, I fhall defer giving a particular defcription of this contrivance, till I am

fully

fully satisfied to what degree of exactness it can be made to answer the end proposed, I am,

Gentlemen,

June 4, 1752.

Your most obedient

humble servant,

J. Ellicott.

LXXXII. *A Description of a new* Tackle *or Combination of* Pullies, *by Mr.* J. Smeaton.

Read June 11, 1752.

THE axis *in peritrochio*, and the compound pulley, are the only mechanic powers, which can with convenience be applied to the moving large weights, when the height, to which they are intended to be raised, is considerable. The excellence of the former is, their working with little friction; that of the latter, in their being easy to be moved from place to place, and applied *extempore*, as occasion requires.

The present methods of arranging pullies in their blocks may be reduced to two. The first consists in placing them one by the side of another upon the same pin; the other in placing them directly under one another, upon separate pins. But in each of these methods an inconvenience arises, if above 3 pullies are framed in one block. For, according to the first method, if above 3 pullies are placed by the side of one another, as the last line, by which the draught is